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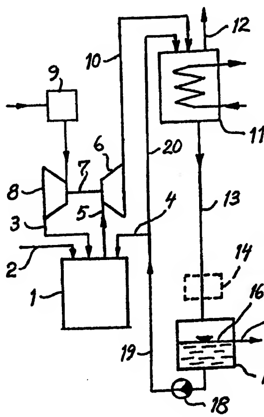
(54) Title: A METHOD OF OPERATING AN INTERNAL COMBUSTION ENGINE ARRANGEMENT AND SUCH AN ARRANGEMENT

(57) Abstract

In the operation of an internal combustion engine arrangement that includes at least one piston engine (1) having at least one combustion chamber, and means (2, 3, 4) for delivering fuel, air and water to the combustion chamber or to each combustion chamber, water vapour present in the engine exhaust gases is condensed by cooling the gases. The water of condensation is returned to the combustion chamber or to each combustion chamber. The arrangement includes to this end cooling means (11) for condensing water vapour in the engine exhaust gases and also means (15, 18, 19, 4) for feeding the condensation water to the combustion chamber or to each combustion chamber.

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# A METHOD OF OPERATING AN INTERNAL COMBUSTION ENGINE ARRANGEMENT AND SUCH AN ARRANGEMENT

The present invention relates to a novel method of operating an internal combustion engine arrangement that includes at least one piston engine having at least one combustion chamber, and means for delivering fuel, air and water to said combustion chamber or to each combustion chamber. The invention also relates to a combustion engine arrangement that works in accordance with the novel method.

It is known that important advantages can be achieved by supplying internal combustion engines with water. These advantages include an increase in efficiency and possible power output, low emission, particularly low $NO_x$ emissions, and low knocking tendencies. Methods and engines of the kind addressed by the present invention that operate with water-injection require large quantities of water. In order to avoid the risk of harmful water-carried salts precipitating out in the engines, the water used will preferably be clean water.

The object of the present invention is to provide a method and an arrangement in which the aforesaid drawbacks are eliminated at least to a substantial extent.

Accordingly, there is proposed to this end in accordance with the invention a method of the kind defined in the introduction in which the exhaust gases are cooled so as to at least partially condense the water vapour present in said exhaust gases and the water thus formed returned to the combustion chamber or to each combustion chamber, optionally after vaporising said water. Condensation of the water vapour and recycling of said water beneficially reduces, or eliminates, the need to supply fresh water.

In accordance with the present invention, an internal combustion engine arrangement that includes at least one piston engine having at least one combustion chamber, and means for delivering fuel, air and water to the combustion chamber, or to each combustion chamber, includes cooling means for condensing water vapour contained in the engine exhaust gases, and means for returning the water of condensation to the combustion chamber, or to each combustion chamber.

Other features characteristic of the invention are set forth in the accompanying dependent Claims and are also made apparent in the following description of exemplifying embodiments of the inventive arrangement shown in the accompanying, schematic drawings, in which

Fig. 1 illustrates schematically a first embodiment of the inventive arrangement; and

Fig. 2 illustrates schematically a second embodiment of the inventive arrangement.

Those components and features illustrated in the Figures that finding mutual correspondence, or generally mutual correspondence, have been identified with the same reference signs.

Fig. 1 illustrates an internal combustion engine arrangement that includes an internal combustion piston-engine 1. Fuel, air and water are delivered to the engine 1 through respective conduits 2, 3 and 4. The water supplied may have been converted to vapour form by means not shown, prior to being delivered to the engine. The engine exhaust gases depart through the conduit 5. The internal combustion engine arrangement may be a stationary arrangement used to run an electric generator and the heat generated used for heating

purposes, for instance. However, the arrangement can also be used with automotive vehicles, for instance. The engine exhaust gases are used to operate a supercharger that includes an exhaust gas turbo 6 which drives , via a shaft 7, a compressor 8 in which the air of combustion is compressed prior to delivery of the air to the engine and to which air arrives via an air filter 9. In the case of Otto engines, air and fuel may be mixed together prior to being delivered to the engine 1, and the air/fuel mixture can be compressed in the supercharger 6, 7, 8 prior to delivery of the mixture to the engine. This procedure is appropriate when using gaseous fuel, such as natural gas, generator gas, landfill gas, etc.

The exhaust gases are delivered from the exhaust turbo 6, either before or after being cleaned, through a conduit 10 to a cooler 11, in which the exhaust gases are cooled to condense a substantial part of their water vapour content. The remainder of the exhaust gases depart through the conduit 12, whereas the water of condensation is delivered through a conduit 13 to a water tank 15, optionally via a filter 14 for extracting water-carried solids. The level of water in the tank 15 is referenced 16 and, as indicated by the arrow 17, the tank 15 may be provided with means for maintaining a determined level of water therein. Water is pumped from the tank 15 to the engine 1 by means of a pump 18, via a conduit 19 and the conduit 4. Water can be pumped via a conduit 20 branching from the conduit 19 to the cooler 11 where the water can be injected directly into the exhaust gases and therewith cool said gases and promote condensation of the water vapour in the exhaust gases and rinse clean the heat-exchange surfaces in the cooler. The water arriving through the conduit 20 and injected into the cooler 11 accompanies the condensate formed in the cooler through the conduit 13 and back to the tank 15. The flow of water in the conduits 4, 19, 20 is controllable, e.g. by means of a valve arrangement not shown.

When operating the internal combustion engine arrangement shown in Fig. 1, the water tank 15 is conveniently filled initially with water to the desired level and the engine 1 then started. It will be realised, however, that as the fuel is combusted in the engine, it will give rise to water vapour that is condensed in the cooler 11, wherewith the condensate thus formed is collected in the tank 15. The exhaust gases may advantageously be cooled in the cooler 11 to such an extent as to obtain sufficient condensate to render the arrangement self-supporting with respect to its water requirement in continuous operation, so as to obviate the need to supply the arrangement with fresh water after possibly filling the tank 15 initially to the level desired. When fresh water is supplied to the arrangement, any salts dissolved in the water are liable to precipitate into the engine. The amount of water delivered to the engine 1 through the conduit 4 may be chosen in dependence on the result desired, but will advantageously be adapted so that said amount will at least correspond to the amount of fuel delivered to the arrangement, and preferably from one to five times as much. When operating an internal combustion engine arrangement fuelled with natural gas, in which water and fuel were delivered to the engine in identical quantities, it was found that equilibrium was reached, i.e. the arrangement became self-supporting with respect to water, when the engine exhaust gases were cooled to about 58°C.

The invention comes particularly into its own when the engine concerned is an Otto engine. In this case, air and fuel can be delivered in stochiometric ratios, whereby very effective exhaust gas purification can be achieved with the aid of a so-called three-path catalyzer. The water supplied to the engine arrangement effectively avoids the typical knocking tendency of the Otto engine and the otherwise high temperature generated in stochiometric combustion, so as to

make overcharging to high pressures possible. This results in greater efficiency and enables the power output of a given engine to be increased. The injection of water results in lower emissions, particularly lower $NO_x$ emissions, irrespective of the type of piston engine concerned, and also a cooling effect that affords higher compression ratios and therewith greater efficiency.

When the exhaust gases are cooled to a temperature of about 55-60°C for instance, the coolant used in the cooler 11 is heated to a relatively low temperature of e.g. about 50-60°C, even when using counterflow cooling in the illustrated manner, which may limit the usefulness of the thermal energy recovered in the cooler. Thermal energy of greater quality can be recovered from the engine exhaust gases, which normally have a temperature in the order of 600-650°C, when the exhaust gases are cooled in more than one stage. In this case, the engine exhaust gases are cooled in a separate, first stage to a temperature that lies above the dew point of the water vapour present in these engine exhaust gases, and then cooled in at least one following stage to condense a desired quantity of water vapour therefrom.

Fig. 2 illustrates a two-stage cooling process in accordance with the above. The internal combustion engine arrangement shown in Fig. 2 is essentially the same as that described with reference to Fig. 1 in other respects and only those parts of the arrangement that differ from the arrangement shown in Fig. 1 will be described. Thus, the Fig. 2 arrangement includes two mutually sequential exhaust gas coolers 21, 22. The engine exhaust gases are delivered to the first cooler 21 at a relatively high temperature, e.g. a temperature of about 600°C, optionally after having first been cleaned. The exhaust gases are cooled indirectly in the cooler 21 to a temperature above the dew point of the water

vapour present in the exhaust gases while recovering high-quality heat therefrom. The exhaust gases are finally cooled in the following cooler 22 while condensing the water vapour present in said gases, partly by heat exchange and partly by injecting water through the conduit 20 in an amount controlled by means of a valve 23. The remainder of the exhaust gases depart from the cooler 22 at 12.

It will be understood that the invention is not restricted to the aforedescribed and illustrated exemplifying embodiments thereof and that the invention can be implemented in any suitable manner within the scope of the inventive concept defined in the following Claims.

## CLAIMS

1. A method of operating an internal combustion engine arrangement that includes at least one piston engine (1) having at least one combustion chamber, and also means (2, 3, 4) for delivering fuel, air and water to the combustion chamber or to each combustion chamber, **characterized** by cooling the exhaust gases such that at least part of the water vapour present in the engine exhaust gases will be condensed, and returning the water of condensation thus formed to the combustion chamber or to each combustion chamber, optionally subsequent to vaporising said condensation water.

2. A method according to Claim 1, **characterized** by delivering at least as much water as fuel, suitably from one to five times as much water.

3. A method according to Claim 1 or Claim 2, **characterized** by first cooling the engine exhaust gases in a separate stage (21) to a temperature that lies above the dew point of the water vapour present in the engine exhaust gases.

4. A method according to any one of Claims 1-3, **characterized** by cooling the exhaust gases by injecting water thereinto, suitably condensation water obtained from said exhaust gases.

5. A method according to any one of Claims 1-4, **characterized** in that the piston engine, or each piston engine (1), is an Otto cycle engine to which fuel and air are delivered in at least substantially stochiometric ratios.

6. An internal combustion engine arrangement that includes at least one piston engine (1) having at least one combustion chamber, and means (2, 3, 4) for delivering fuel, air and

water to the combustion chamber or to each combustion chamber, **characterized** by cooling means (11; 21, 22) for condensing water vapour from the engine exhaust gases, and means (15, 18, 19, 4) for returning the water of condensation to the combustion chamber or to each combustion chamber.

7. An arrangement according to Claim 6, **characterized** by a condensate collecting vessel (15) which is connected downstream of said cooling means (11; 21, 22) and from which condensation water is cycled back to the combustion chamber or to each combustion chamber.

8. An arrangement according to Claim 6 or 7, **characterized** in that said cooling means (11; 21, 22) includes at least one cooler (11; 22) through which the exhaust gases flow, and which uses water injected thereinto as a coolant.

9. An arrangement according to Claim 8, **characterized** in that said cooling means (21, 22) includes a first cooler (21) in which indirect heat exchange is effected between the engine exhaust gases and the coolant, such as to cool the gases to a temperature above their dew point, and a second, following cooler (22) in which water vapour present in the exhaust gases is condensed, said second cooler preferably operating with direct injection of coolant into the exhaust gases.

10. An arrangement according to any one of Claims 6-9, **characterized** in that the piston engine or each piston engine (1) is an Otto cycle engine that operates with an at least substantially stochiometrical fuel/air ratio.

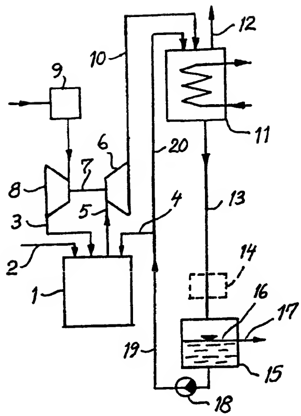
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Fig. 1

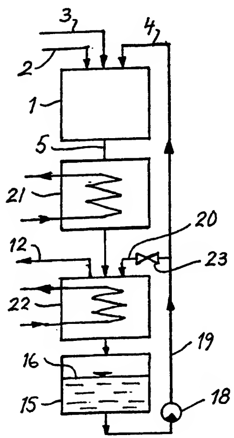
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Fig. 2

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/01377

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC6: F02M 25/022

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC6: F02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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**INTERNATIONAL SEARCH REPORT**
Information on patent family members

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